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Original Article

Comparison of 3 Different Endoscopic Techniques for Lumbar Spinal Stenosis: Comprehensive Radiological and Clinical Study

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Objective: This study aimed to compare the clinical and comprehensive radiological outcomes of 3 types of endoscopic decompression surgery: unilateral biportal endoscopic lumbar decompression (UBELD), microendoscopic laminotomy (MEL), and percutaneous endoscopic lumbar decompression (PELD).
Methods: Patients with single-level lumbar spinal stenosis without instability were included in this multicenter retrospective study. Visual analogue scale (VAS) scores for each extremity, VAS back pain, and Japanese Orthopaedic Association (JOA) scores at preoperative and postoperative 1st, 6th, and 12th months were used as clinical outcome measures. In order to compare the radiological results of the patients, bilateral superior articular distance (SAD), bilateral lateral recess height (LR height), bilateral lateral recess angle (LR angle), and cross-sectional spinal canal area values were measured.
Results: Eighty patients in the UBELD group, 73 patients in the MEL group, and 62 patients in the PELD group were included in the study. There was a statistically significant improvement in VAS scores and JOA scores in all groups compared to the preoperative period. At the 12th month postoperatively, the highest lateral decompression values on the approach side were determined as MEL (SAD: 4.1 mm, LR angle: 38.8°, LR height: 4.0 mm), followed by UBELD (SAD: 3.6 mm, LR angle: 36.2°, LR height: 3.3 mm) and PELD (SAD: 3.0 mm, LR angle: 21.7°, LR height: 2.3 mm), respectively. For the contralateral side, the highest lateral recess decompression values were listed as UBELD > MEL > PELD.
Conclusion: Effective decompression can be performed using all endoscopic techniques in lumbar spinal stenosis. However lateral recess decompression values were found to be better in UBELD and MEL techniques, compared to PELD.

Keywords: Lumbar spinal stenosis, Endoscopic decompression, Unilateral biportal endoscopic lumbar decompression, Microendoscopic laminotomy, Percutaneous endoscopic lumbar decompression

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INTRODUCTION

Lumbar spinal stenosis is a lumbar degenerative disease commonly observed in the elderly population, resulting from the narrowing of neural structures within the spinal canal by surrounding soft tissues and bone structures. Clinical manifestations can present as lower back pain, leg pain, neurogenic claudication, and neurological dysfunction such as cauda equine syndrome.[1,2] Surgical treatments are considered for patients experiencing severe pain and/or neurological symptoms that do not respond to

conservative therapy. Many studies have reported successful results with surgical decompression in cases which were refractory to conservative management.[3-5]

Decompression with laminectomy has been used in surgical treatment for many years. However, in this technique, chronic low back pain is frequently encountered as a result of extensive muscle dissection, instability due to removal of the posterior ligamentous complex and facet joints, and additional damage to the lumbar back muscles, which are already atrophic due to age. Instrumented spinal stabilization, with or without fusion, is often performed to correct this iatrogenic instability. It is known that implant-related problems, adjacent segment disease, pseudoarthrosis, infection and chronic back pain may occur in the postoperative period. In a patient group that already has high comorbidities, such problems could lead to additional health complications.[1,6,7]

Microscopic unilateral laminotomy for bilateral decompression (ULBD) technique was first described by Poletti et al.[8] in 1995. With the help of this technique, bilateral decompression can be performed unilaterally with minimal dissection on one side, without damaging the integrity of the posterior bone structures of the spine and facet joints. In this way, effective neural decompression can be performed without creating additional instability in the spine and there is no need for additional stabilization surgery.[5,9,10] ULBD is less invasive than traditional decompressive surgeries and causes less damage to the posterior musculo-ligamentous structures, resulting in faster recovery and less chronic low back pain.[1,11] In 2002, Khoo and Fessler[12] first applied the ULBD technique microendoscopically, which was previously applied microscopically. While microendoscopy is a minimally invasive endoscopic technique designed for discectomy, Khoo and Fessler[12] modified this method for spinal stenosis for the first time and defined this newly modified technique as microendoscopic decompressive laminotomy. Over time, the ULBD technique has begun to be frequently applied among other endoscopic spinal surgery techniques under the names of percutaneous endoscopic lumbar decompression (PELD) and unilateral biportal endoscopic lumbar decompression (UBELD).[13-19]

The microendoscopic laminotomy (MEL) technique is performed using a tubular retractor. Endoscope and surgical instruments are advanced through the tubular retractor.[5,9,10,12] In the PELD technique, there is a single portal, and a specialized endoscope is used that contains channels for instrumentation, visualization and irrigation.[13-18] UBELD technique involves 2 separate unilateral portals for viewing and working. The endoscope is inserted through the cranial (viewing) portal, while instruments are advanced through the caudal (working) portal.[13,20-22] All these techniques share the same purpose and philosophy. These methods are referred to as "lumbar endoscopic ULBD" in the AO Spine consensus paper on nomenclature.[23]

Fundamentally, the aim of all endoscopic techniques (MEL, PELD, UBELD) is to provide rapid and early recovery in a minimally invasive manner. There are numerous studies in the literature comparing these 3 techniques with open microsurgical methods. It has been reported in many studies that endoscopic techniques cause less muscle damage and faster recovery than microsurgical techniques.[5,9,20,24] Although each technique having its own advantages, to our knowledge, there is currently no study in the literature that comprehensively compares these 3 commonly used endoscopic techniques for spinal stenosis surgery, both radiologically and clinically. Therefore, the current study aims to compare the clinical and radiological outcomes of these 3 types of endoscopic decompression surgery: UBELD, MEL, PELD (monoportal endoscopic technique).

MATERIALS AND METHODS

This study was a retrospective analysis of prospectively collected data on patients treated in the period from January 2017 to May 2020. Patients with clinically and radiologically confirmed single-level lumbar spinal stenosis without instability were included in this multicenter retrospective study. This research was performed after the ethics committee approval of from the Ankara University Faculty of Medicine (Decision number: i10-697-23). Written informed consent was obtained from all individual participants included in the study.

This study included patients who fulfilled all the following inclusion criteria: (1) radiologically proven single-level lumbar spinal stenosis in magnetic resonance imaging (MRI), (2) bilateral lower limb neurogenic claudication, (3) bilateral radicular leg pain with leg pain VAS scores close to each other (±1 VAS score) in both lower limbs, (4) undergoing UBELD, MEL, or PELD procedures by a surgeon experienced in endoscopic spinal surgery, (5) at least 12 months of follow-up period. The criteria for exclusion were as follows: (1) multilevel lumbar spinal stenosis in MRI, (2) cases with accompanying significant adjacent segment foraminal/extraforaminal stenosis, (3) cases in which discectomy was performed during the operation, (4) previous history of spinal surgeries, (5) patients who had a deformity with a Cobb angle of > 10°, (6) patients with lumbar instability (translation of 4 mm or 10° of angular motion in dynamic lumbar *x*-rays), (7) cases with space occupying lesions in the

spinal canal, (8) patients with a follow-up duration of less than 12 months, (9) patients whose clinical scores and radiological measurements could not be accessed from hospital records, (10) cases with intraoperative dural injury or postoperative hematoma paralysis.

The study was carried out at 2 medical institutions. All surgical procedures were performed by spine surgeons with a minimum of 5 years of endoscopic surgery experience. In total, 5 experienced spine surgeons participated in the study. UBELD, MEL, and PELD procedures were performed. The type of the operative procedure was determined according to the preference and experience of the surgeon. All 3 endoscopic decompression techniques were applied adhering to the principles of ULBD. UBELD technique involves 2 separate unilateral portals for viewing and working. The endoscope is inserted through the cranial (viewing) portal, while instruments such as a burr, radiofrequency ablation probe, and Kerrison punches are advanced through the caudal (working) portal. In the MEL technique, a tubular retractor (METRx system; Medtronic Sofamor Danek, Memphis, TN, USA) is used. Endoscope and surgical instruments are inserted through the tubular retractor. In PELD technique, there is a single portal and only one uniportal endoscope is used. This endoscope (PSLD; Maxmore Co., Ltd., Unterfoehring, Germany) involves channels for instrumentation, visualization and irrigation. Fluoroscopic images of 3 different techniques were presented in Supplementary Fig. 1. We classified patients into 3 groups based on the surgical approach they had undergone by examining the operation reports in hospital records.

The preoperative and postoperative radiological images of the patients were evaluated, including anteroposterior and lateral flexion-extension radiographs, computed tomography (CT) scans, and magnetic resonance images. MRI examinations were performed in all patients preoperatively, at postoperative 1st day, and at postoperative 12th months. The radiological measurements were made using a DICOM viewer (POP-net webserver, Image ONE Co., Tokyo, Japan). Measurements were conducted using transverse T2-weighted MRI images of the most stenotic level. The spinal canal area (SCA) measurement was made from middisc level to evaluate central canal stenosis. SCA values were recorded using the automatic area calculation program of the DICOM viewer. It is determined by measuring the space between the vertebral body and the ligamentum flavum in the MRI section. On the other hand, lateral recess measurements were taken from the axial MRI sections at the level of the superior vertebral end plate. Lateral recess angle is the angle between the lines paralel to the floor and and the roof of the lateral recess in T2 weighted axial MRI. Lateral recess height is a distance between the posterior border of the vertebral body and the most anterior point of the superior articular facet in the MRI section. CT scans were also obtained preoperatively and postoperatively. Superior articular distance (SAD) values for the operation level were recorded using axial CT images. SAD is a parameter obtained from axial CT scan that defines the distance between the superior articular facet and the vertebral body. Since these are the most preferred radiological parameters in similar studies in the literature, these values were recorded. The rationale for using the values of the LR angle, LR height, and SAD was to evaluate lateral recess decompression. The measurement techniques were explained in Fig. 1.

All of these radiological measurements were performed by 5 spinal surgeons blinded to patient information. The average values of these measurements were used in the analyses. We recorded measurements of LR angle, LR height, and SAD for both the approach side where laminotomy was applied and the contralateral side. We expressed these measurements as ipsilateral and contralateral values (e.g., ipsilateral LR angle, contralateral LR angle, etc.). In this way, we aimed to compare the decompression values on the approach side and contralateral side among different surgical techniques.

Clinical healing was evaluated using the Japanese Orthopaedic Association (JOA) score and the visual analogue scale (VAS) score, administered preoperatively and at the 1st, 3rd, and 12th months postoperatively. The JOA score improvement rate was calculated using the formula: Improvement rate (%) = (postoperative JOA score–preoperative JOA score) × 100/(29–preoperative JOA score). The VAS was applied under 3 separate subheadings: low back pain VAS, ipsilateral leg pain VAS, and contralateral leg pain VAS. We included patients whose preoperative VAS scores in both legs were close to each other (within ± 1 VAS score). On the other hand, we excluded the patients whose preoperative ipsilateral and contralateral leg pain VAS scores were not close to each other and who felt pain predominantly in one leg. We aimed to evaluate decompression in both lateral recesses, including the approach side (ipsilateral) and the contralateral side. Therefore, we excluded the patient group with findings predominantly on one leg. We also excluded cases with intraoperative dura injury or postoperative hematoma paralysis to avoid inaccurately affecting clinical scores.

Statistical analysis was performed using IBM SPSS Statistics ver. 22.0 (IBM Co., Armonk, NY, USA). Descriptive statistics were used to characterize demographic variables of patients.

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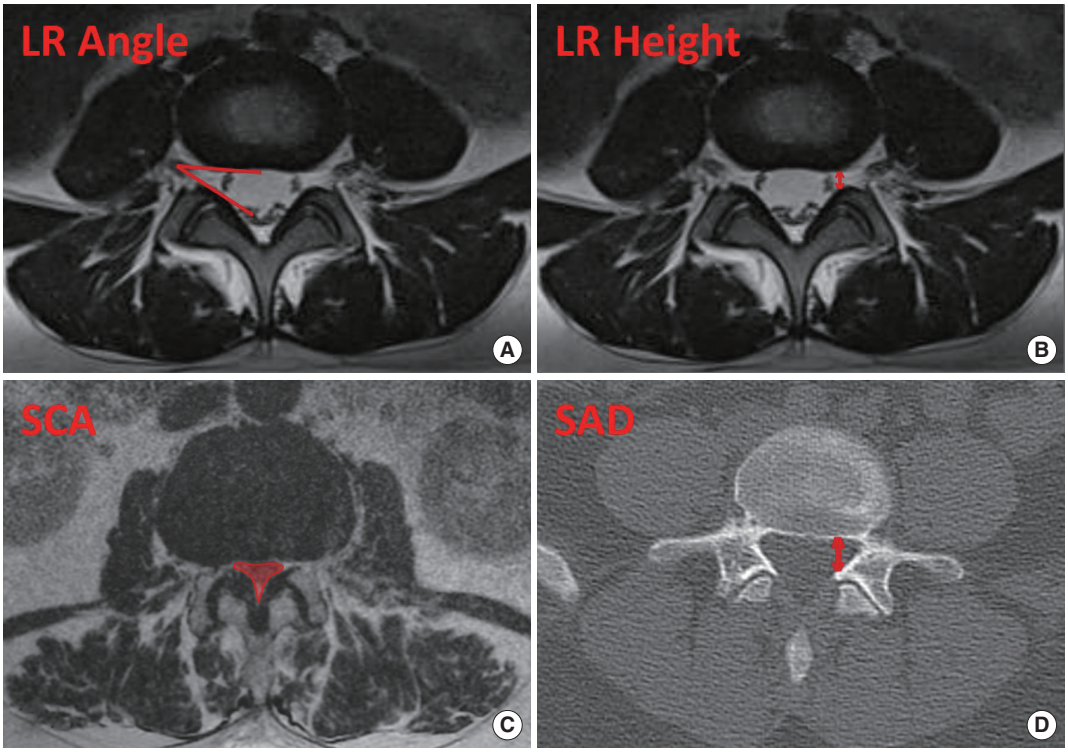


Fig. 1. The measurements of radiological parameters (lateral recess angle, lateral recess height, spinal canal area and superior articular distance). (A) Lateral recess (LR) angle is the angle between the lines paralel to the floor and and the roof of the lateral recess in T2-weighted axial magnetic resonance imaging (MRI). (B) LR height is a distance between the posterior border of the vertebral body and the most anterior point of the superior articular facet in the MRI section. (C) Spinal canal area (SCA) is determined by measuring the space between the vertebral body and the ligamentum flavum in the MRI section. (D) Superior articular distance (SAD) is a parameter obtained from axial computed tomography scan that defines the distance between the superior articular facet and the vertebral body.

Mean, median and standard deviation values were used to show descriptive statistics. One way analysis of variance (ANOVA) and repeated measures ANOVA tests were applied to compare the clinical and radiological outcomes of the groups. For post hoc analysis, Tamhane and Tukey tests were applied. Continuous and categorical parameters were analyzed using the t-test and chi-squared test, respectively. p-values <0.05 were considered statistically significant. The study was performed in accordance with the Declaration of Helsinki and the STROBE guidelines.

RESULTS

A total of 215 patients were evaluated in this study. The patients consisted of 127 males (59.1%) and 88 females (40.9%) with a mean age of 68.4 years. Eighty patients in the UBELD group, 73 patients in the MEL group, and 62 patients in the PELD group who met the inclusion criteria were evaluated in the study (The patient characteristics were presented in detail in Supplementary Table 1). The minimum follow-up time was 12 months.

Changes in VAS scores from the preoperative to the 12-month postoperative period were presented in Table 1 and Supplementary Fig. 2. There was a statistically significant improvement in VAS scores in all groups compared to the preoperative period. The preoperative low back pain VAS scores in the groups were 4.6, 4.58, and 4.65, respectively, while these values were observed to be 0.41, 0.38, and 0.31 at postoperative 12th months. There was no significant difference in terms of low back pain VAS score among the groups during the preoperative and postoperative periods ($p=0.945$, $p=0.436$, respectively). Significant improvement in low back pain VAS score was observed over time in all 3 surgical groups ($p<0.05$) (Supplementary Fig. 2A). In terms of ipsilateral leg pain VAS, no significant difference was observed between the groups in the preoperative period and in the postoperative 1st and 6th months. However, at postoperative 12th months, it was significantly lower in the MEL group than in the UBELD or PELD group (both $p<0.05$) (Supplementary

Table 1. Alteration of visual analogue scale (VAS) scores over time in groups

Variable	UBELD	MEL	PELD	p-value	Pairwise comparison (p-value)		
					UBELD→MEL	UBELD→PELD	MEL→PELD
Low back pain VAS							
Preop.	4.6 ± 1.14	4.58 ± 1.29	4.65 ± 1.19	0.945	NS	NS	NS
Postop. 1st month	1.28 ± 0.73	1.16 ± 0.76	1.05 ± 0.61	0.170	NS	NS	NS
Postop. 6th month	0.75 ± 0.61	0.47 ± 0.55	0.65 ± 0.60	0.012*	0.009*	0.544	0.184
Postop. 12th month	0.41 ± 0.52	0.38 ± 0.49	0.31 ± 0.46	0.436	NS	NS	NS
Ipsilateral leg pain VAS							
Preop.	6.50 ± 0.95	6.36 ± 1.52	6.18 ± 1.34	0.332	NS	NS	NS
Postop. 1st month	2.55 ± 0.98	2.68 ± 1.90	2.32 ± 1.96	0.438	NS	NS	NS
Postop. 6th month	2.34 ± 0.97	1.99 ± 1.77	2.35 ± 2.20	0.331	NS	NS	NS
Postop. 12th month	3.09 ± 1.00	1.33 ± 1.38	2.44 ± 2.41	< 0.001*	< 0.001*	0.139	0.006*
Contralateral leg pain VAS							
Preop.	5.81 ± 0.93	6.11 ± 1.87	5.90 ± 1.26	0.416	NS	NS	NS
Postop. 1st month	1.78 ± 0.97	2.32 ± 1.96	3.45 ± 0.56	< 0.001*	0.104	< 0.001*	< 0.001*
Postop. 6th month	1.61 ± 0.89	2.19 ± 1.97	2.76 ± 0.86	< 0.001*	0.068	< 0.001*	0.084
Postop. 12th month	2.53 ± 0.90	2.25 ± 1.83	2.58 ± 0.97	0.268	NS	NS	NS

Values are presented as mean ± standard deviation.
UBELD, unilateral biportal endoscopic lumbar decompression; MEL, microendoscopic laminotomy; PELD, percutaneous endoscopic lumbar decompression; NS, nonsignificant; Preop., preoperative; Postop., postoperative.
Analysis of variance test was used to assess the potential differences between groups.
*$p < 0.05$, statistically significant differences.

Table 2. Alteration of Japanese Orthopaedic Association (JOA) scores over time in groups

JOA score	UBELD	MEL	PELD	p-value	Pairwise comparison (p-value)		
					UBELD→MEL	UBELD→PELD	MEL→PELD
Preop.	12.19 ± 2.36	10.19 ± 5.40	11.89 ± 5.11	0.014*	0.013*	0.964	0.179
Postop. 1st month	19.71 ± 3.19	18.78 ± 5.26	18.50 ± 5.44	0.258	NS	NS	NS
Postop. 6th month	20.10 ± 3.28	19.74 ± 4.83	18.92 ± 5.75	0.315	NS	NS	NS
Postop. 12th month	21.49 ± 3.19	20.07 ± 4.49	19.05 ± 5.63	0.005*	0.080	0.009*	0.582
Improvement (%)	55.21 ± 18.11	52.99 ± 21.00	42.19 ± 28.07	0.002*	0.865	0.006*	0.042*

Values are presented as mean ± standard deviation.
UBELD, unilateral biportal endoscopic lumbar decompression; MEL, microendoscopic laminotomy; PELD, percutaneous endoscopic lumbar decompression; NS, nonsignificant; Preop., preoperative; Postop., postoperative.
Analysis of variance test was used to assess the potential differences between groups.
*$p < 0.05$, statistically significant differences.

Fig. 2B, Table 1). In terms of contralateral leg pain VAS scores, significantly lower values were observed in the UBELD group compared to the PELD group at postoperative 1st and 6th months (both $p < 0.001$) (Supplementary Fig. 2C, Table 1).

Alteration of JOA scores over time in groups were presented in Table 2 and Supplementary Fig. 3. There was a statistically significant improvement in JOA scores in all groups compared to the preoperative period (Supplementary Fig. 3). At the end of the 12th month, the patients in the UBELD (JOA improvement: 55.2%) group had the highest clinical improvement rate, followed by MEL (52.9%) and PELD (42.9%), respectively. The JOA improvement rates were significantly higher in UBELD and MEL compared to PELD ($p = 0.002$) (Table 2).

Changes in values of radiological parameters used to assess decompression on the approach side were presented in Table 3 and Supplementary Fig. 4. There was no significant difference among the groups in the preoperative measurements of ipsilateral SAD, ipsilateral LR angle, and ipsilateral LR height values.

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Table 3. Alterations of radiological parameters measured from the ipsilateral side of the operation area

Variable	UBELD	MEL	PELD	p-value	Pairwise comparison (p-value)		
					UBELD→MEL	UBELD→PELD	MEL→PELD
Ipsilateral SAD							
Preop.	2.47 ± 0.59	2.37 ± 0.99	2.58 ± 1.14	0.419	NS	NS	NS
Postop. 12th month	3.64 ± 1.03	4.19 ± 1.02	3.07 ± 1.06	< 0.001*	0.003*	0.004*	< 0.001*
Ipsilateral LR angle							
Preop.	18.71 ± 6.56	17.51 ± 7.82	18.89 ± 6.46	0.443	NS	NS	NS
Postop. 1st day	46.03 ± 9.55	42.22 ± 10.87	29.53 ± 6.27	< 0.001*	0.069*	< 0.001*	< 0.001*
Postop. 12th month	36.28 ± 8.83	38.87 ± 10.76	21.77 ± 4.34	< 0.001*	0.289	< 0.001*	< 0.001*
Ipsilateral LR height							
Preop.	1.75 ± 0.58	1.99 ± 0.88	2.13 ± 0.91	0.075	NS	NS	NS
Postop. 1st day	4.13 ± 1.09	4.33 ± 0.92	2.88 ± 0.57	< 0.001*	0.534	< 0.001*	< 0.001*
Postop. 12th month	3.36 ± 0.86	4.0 ± 0.89	2.39 ± 0.46	< 0.001*	< 0.001*	< 0.001*	< 0.001*

Values are presented as mean ± standard deviation.
UBELD, unilateral biportal endoscopic lumbar decompression; MEL, microendoscopic laminotomy; PELD, percutaneous endoscopic lumbar decompression; NS, nonsignificant; Preop., preoperative; Postop., postoperative; SAD, superior articular distance; LR, lateral recess.
Analysis of variance test was used to assess the potential differences between groups.
*$p < 0.05$, statistically significant differences.

All these 3 radiologic parameters (SAD, LR angle, LR height) measured from the ipsilateral side demonstrated a significant increase in UBELD, MEL and PELD groups in the postoperative period ($p < 0.05$). The highest values of the LR angle and LR height were observed at postoperative 1st day in all 3 surgical groups (Supplementary Fig. 4). In all of these groups, there was a decrease in LR angle and LR height values at the postoperative 12th month compared to the postoperative 1st day ($p < 0.05$). Postoperative 12th month mean ipsilateral SAD value was 3.64 mm in the UBELD group, 4.19 mm in the MEL group and 3.07 mm in the PELD group. In terms of ipsilateral SAD values, the highest decompression was observed to be MEL > UBELD > PELD ($p < 0.001$) (Table 3). Postoperative 12th month mean ipsilateral LR angle was 36.28° in the UBELD group, 38.87° in the MEL group and 21.77° in the PELD group. Decompression was observed to be significantly higher in the MEL and UBELD groups compared to PELD according to ipsilateral LR angle values ($p < 0.001$) (Table 3). Postoperative 12th month mean ipsilateral LR height was 3.36 mm in the UBELD group, 4.0 mm in the MEL group and 2.39 mm in the PELD group. Ipsilateral LR height values revealed the highest decompression in the order of MEL > UBELD > PELD ($p < 0.001$) (Table 3).

Changes in values of radiological parameters (SAD, LR angle, LR height) measured from the contralateral side of the operation area were presented in Table 4 and Supplementary Fig. 5. All these 3 radiologic parameters measured from the contralateral side demonstrated a significant increase in UBELD, MEL, and PELD groups in the postoperatively compared to preoperative period ($p < 0.05$). The peak values for contralateral LR angle and contralateral LR height were observed in all 3 surgical groups at the 1st day postoperatively (Supplementary Fig. 5). However, in each of these groups, a decline in both LR angle and LR height values was observed at postoperative 12th month compared to the postoperative 1st day ($p < 0.05$). Postoperative 12th month mean contralateral SAD value was 4.04 mm in the UBELD group, 4.05 mm in the MEL group and 2.59 mm in the PELD group. Contralateral SAD values indicated a significantly higher level of decompression in the UBELD and MEL groups compared to the PELD group ($p < 0.001$) (Table 4). Postoperative 12th month mean contralateral LR angle was 46.81° in the UBELD group, 40.82° in the MEL group and 21.16° in the PELD group. In terms of contralateral LR angle values, the highest decompression was observed in the order of UBELD > MEL > PELD ($p < 0.001$) (Table 4). Postoperative 12th month mean contralateral LR height was 4.38 mm in the UBELD group, 4.2 mm in the MEL group and 2.2 mm in the PELD group. According to contralateral LR height values, the level of decompression was significantly higher in the UBELD and MEL groups compared to the PELD group ($p < 0.001$) (Table 4).

Alterations in cross-sectional SCAs were presented in Supplementary Table 2 and Supplementary Fig. 6. At the postoperative 1st day, SCAs significantly expanded in each of the 3 groups:

Table 4. Alterations of radiological parameters measured from the contralateral side of the operation area

Variable	UBELD	MEL	PELD	p-value	Pairwise comparison (p-value)		
					UBELD→MEL	UBELD→PELD	MEL→PELD
Contralateral SAD							
Preop.	2.53±0.70	2.24±0.74	2.46±0.86	0.052	NS	NS	NS
Postop. 12th month	4.04±1.19	4.05±1.01	2.59±0.81	<0.001*	0.997	<0.001*	<0.001*
Contralateral LR angle							
Preop.	18.53±5.44	17.74±7.69	19.94±7.11	0.165	NS	NS	NS
Postop. 1st day	56.78±8.92	44.26±10.26	24.81±5.49	<0.001*	<0.001*	<0.001*	<0.001*
Postop. 12th month	46.81±7.39	40.82±10.48	21.16±4.77	<0.001*	<0.001*	<0.001*	<0.001*
Contralateral LR height							
Preop.	1.72±0.56	1.96±0.81	1.92±0.80	0.017*	0.156	0.016*	0.737
Postop. 1st day	5.23±1.06	4.55±1.12	2.61±0.55	<0.001*	0.001*	<0.001*	<0.001*
Postop. 12th month	4.38±0.75	4.20±1.08	2.20±0.48	<0.001*	0.560	<0.001*	<0.001*

Values are presented as mean±standard deviation.
UBELD, unilateral biportal endoscopic lumbar decompression; MEL, microendoscopic laminotomy; PELD, percutaneous endoscopic lumbar decompression; NS, nonsignificant; Preop., preoperative; Postop., postoperative; SAD, superior articular distance; LR, lateral recess.
Analysis of variance test was used to assess the potential differences between groups.
*$p<0.05$, statistically significant differences.

from 0.63 to 2.41 cm^2 in the UBELD group, from 0.69 to 2.29 cm^2 in the MEL group, and from 0.57 to 2.07 cm^2 in the PELD group. Accordingly, there was no difference between UBELD and MEL in terms of SCA, while both had statistically significantly higher decompression values compared to the PELD group ($p<0.001$) (Supplementary Table 2). At the postoperative 12th month, each of these groups showed a decrease in SCA values compared to the postoperative 1st day ($p<0.05$).

Lateral recess decompressions on the ipsilateral and contralateral sides of the surgical area were compared radiologically in Supplementary Table 3. In the UBELD group, radiologic measurements of the lateral recess decompressions (SAD, LR angle, LR height) were observed to be higher in the contralateral to the approach side ($p<0.001$). UBELD provides sufficient decompression on both the ipsilateral and contralateral sides. However, it was observed that contralateral lateral recess decompression was more effective in the UBELD group. In the MEL technique, no significant differences were observed in terms of lateral recess decompression between the ipsilateral and contralateral sides. In the PELD technique, it was observed that lateral recess decompression measurements on the ipsilateral side were higher compared to the contralateral side (Supplementary Table 3).

Postoperative instability did not occur in any patient during the 12-month follow-up period. We experienced perioperative complications such as dural injury and postoperative epidural hematoma. We excluded these patients who developed dural tear or hematoma paralysis to avoid adversely affecting the comparison of clinical scores between groups. Postoperative hematoma paralysis was observed in 4 cases for the MEL group, 2 cases for the PELD group, and 1 case for the UBELD group. Although there was no significant difference due to the insufficient number of cases, MEL resulted in a higher number of hematoma paralysis. On the other hand, intraoperative dural injury was observed in 2 cases for the MEL group, 2 cases for the UBELD group, and 3 cases for the PELD group. There was no significant difference in the incidence of dural tear among the 3 groups ($p>0.05$).

DISCUSSION

As a result of advancements in endoscopic techniques, endoscopy is becoming a popular surgical approach in spine surgery, as in various other surgical disciplines. Endoscopic spine surgeries are minimally invasive techniques applied as alternative methods to traditional open surgeries.[9,10,13,21] Minimally invasive surgeries have gained importance in the treatment of spinal stenosis due to the undesirable outcomes associated with traditional open surgeries, such as extensive muscle dissection, facet destruction, iatrogenic instability, implant-related problems, and chronic low back pain.[1,6,7]

There are numerous studies in the literature comparing endoscopic techniques (MEL, PELD, UBELD) with microscopic

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ULBD or traditional open decompression. In most of these studies, it has been stated that endoscopic spinal surgical techniques can be applied as safe and effective minimal invasive methods in the treatment of spinal stenosis.[9,12,15,22] However, there are few studies comparing these endoscopic methods with each other both radiologically and clinically. Ito et al.[25] compared MEL with UBELD in their study involving 181 cases with 1-level lumbar canal stenosis. In the final period, VAS scores and Oswestry Disability Index (ODI) significantly decreased in both groups, and there was no significant difference in clinical scores between the groups. They reported that the facet preservation rates were higher in UBELD compared to MEL. In the MEL technique, the range of instrument movement is limited because the surgical instruments are confined within a tubular retractor. On the other hand, UBELD, which does not utilize a tubular retractor, offers high flexibility in maneuvering instruments. Ito et al. have noted that this situation may have contributed to a higher facet preservation rate in UBELD.[25] Heo et al.[13] compared decompression outcomes among UBELD, PELD (uniportal endoscopy), and microsurgery, and they concluded that both UBELD and PELD demonstrated significantly lower back pain VAS scores than microsurgery in the early postoperative stage. However, there were no significant differences in the VAS scores or ODI at the final follow-up among the 3 groups. They also mentioned that mean dural expansion in the PELD group was significantly lower than that in the microscopy or UBELD group.[13]

In our study, unlike existing studies in the literature, all 3 endoscopic decompression methods (UBELD, MEL, PELD) were comprehensively compared with each other both radiologically and clinically. The multicenter design of our study allowed us to create a comprehensive database related to 3 different surgical methods. We observed statistically significant improvement in VAS and JOA scores in all groups compared to the preoperative period, consistent with the literature. We also observed that effective decompression was achieved in all endoscopic techniques according to radiological measurements. However, radiological measurements related to lateral recess decompression (SAD, LR angle, LR height) were found to be lower in the PELD group compared to UBELD and MEL. In the PELD technique, minimal sized instruments can be used due to the small diameter of the outer canula and working channel. On the other hand, in UBELD and MEL techniques, large sized instruments such as Kerrison punches can be used. This situation facilitates decompression in UBELD and MEL. Additionally, PELD is a uniportal technique and the confinement of surgical instruments within the outer canula limits the range of instrument movement. PELD also has a narrower field of view and a more limited working area compared to other endoscopic methods.[26] Therefore, lateral recess decompression is more challenging in the PELD technique.

One of the primary objectives of this study was to compare the values of lateral recess decompression on the approach side and the contralateral side among surgical techniques. In the UBELD group, radiologic measurements of the lateral recess decompressions (SAD, LR angle, LR height) were observed to be higher in the contralateral to the approach side. In addition, UBELD was found to be the most effective method for contralateral lateral recess decompression. UBELD is a biportal technique, and the separate working and viewing portals provide a geometrical advantage for contralateral recess decompression. The separation of the working portal from the viewing portal allows independent movement of surgical instruments from the endoscope. This condition enhances the maneuverability of the instruments in the UBELD technique. The separated viewing portal in UBELD also allows the endoscope to better visualize the contralateral side. Some recent literature suggests that endoscopic decompression is more easily accessible from the contralateral side of pathology using the UBELD technique.[27,28] Yeung et al.[27] have stated that unilateral biportal decompression via the contralateral approach may offer better lateral recess clearance compared to the ipsilateral approach. Heo et al.[28] reported that the contralateral side was well visualized by tilting the endoscope during UBELD. They also reported that biportal endoscopic contralateral decompression minimizes iatrogenic facet violation in pathologies such as juxtafacet cystic lesions.

In our study, we observed that decompression values (SCA, LR angle, LR height) decreased in the postoperative 12th month compared to the postoperative 1st day in all 3 surgical groups. Spinal stenosis is a chronic degenerative disease, and the continuation of the degenerative process after surgery may have led to this condition. A second possible reason that could lead to this condition is the formation of fibrotic tissues during the resolution of postoperative hematoma. Ikuta et al.[29] evaluated 30 patients who underwent MEL in terms of postoperative hematoma. They reported that dural sac expansion was less in the patient group with postoperative symptomatic hematoma. They also mentioned that fibrotic tissues could have prevented the dural sac re-expansion. We also believe that the decrease in radiological decompression parameters observed from the first postoperative day to 12th months is related to postoperative fibrosis. However, this decrease is limited to radiological values, and clinical outcomes have not been affected in postoperatively.

In light of the studies in the literature, it has been observed that postoperative hematoma cases are most frequently reported for MEL among endoscopic techniques.[25,29,30] As the levels of invasiveness of the techniques increase, it is known that exposure to radiation decreases but the likelihood of hematoma increases.[25,26] Merter and Shibayama[30] evaluated 245 patients who underwent MEL for single-level spinal stenosis in terms of spinal epidural hematoma (SEH). They reported that patients with higher hematoma grades had lower clinical scores. They also mentioned that due to poor visualization in the surgical field, achieving effective hemostasis was challenging, and this situation increased the likelihood of postoperative SEH in the MEL technique. Ito et al.[25] also reported that MEL resulted in a greater number of hematoma paralysis cases compared to UBELD. In our study, although no significant difference was found, MEL resulted in a higher number of hematoma paralysis. The use of irrigation fluid in UBELD and PELD techniques enhances image quality. Therefore, more effective hemostasis may be achieved in these techniques compared to MEL.

The major limitation of our study was the limited number of sample size and the retrospective design of the research. Another limitation was that the surgical techniques in our study were not performed by the same surgeon. In order to avoid bias, we included only cases from spine surgeons with at least 5 years of endoscopic surgery experience. The strength of our research is that it is the first study in which 3 endoscopic decompression techniques (UBELD, MEL, PELD) were compared radiologically and clinically. Another limitation of our study was the lack of data on the learning curve of these techniques. A prospective study with a larger sample size would be more informative.

CONCLUSION

We were able to achieve significant lumbar canal decompression with all 3 endoscopic techniques. Clinical scores and radiological measurements significantly improved in all groups compared to the preoperative period. However, radiological measurements related to lateral recess decompression, were found to be better in UBELD and MEL techniques compared to PELD. UBELD, with its greater freedom of hand movement and high visual capacity, was found as the most effective method for contralateral lateral recess decompression.

NOTES

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